Possible Existence and Detection of Strangeness - 4 Dibaryon States

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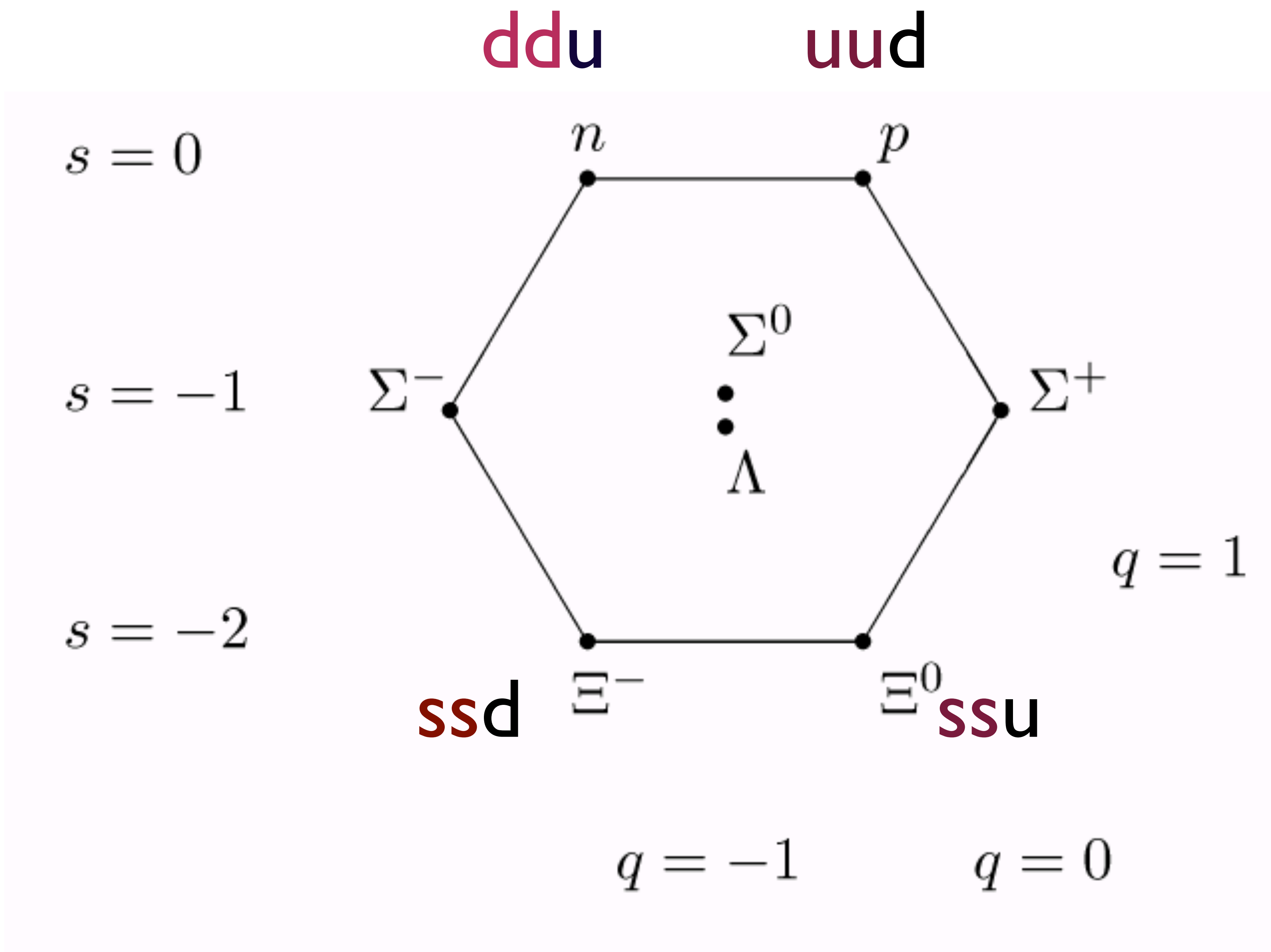
Outline

- SU(3) flavor $\longrightarrow$ $\Xi\Xi$ bound $^1S_0$ state
- NN, $\Xi\Xi$ each in {27} dim. rep of SU(3)
- np: $^1S_0$ nearly bound state a_{np}=-24 fm
- Increase nucleon mass 10%, **same** interaction get bound state
- $\Xi\Xi$, np $^1S_0$ states in same irrep of SU(3)
- $^1S_0$ state: NN, $\Xi\Xi$ similar , increased mass causes bound state
- 3 simplest models predict bound states
- why interaction not depend on quark masses? 6 detailed Nijmegan models predict bound states
- lattice calculation Beane et al 1109.2889 gives bound state
- detection at RHIC

SU(3) flavor symmetry



Unitary (flavor) symmetry for baryon-baryon interactions

- EFT calculation of Savage, Wise Phys.Rev. D53 (1996) 349

$$\Pi = \begin{bmatrix} \pi^0/\sqrt{2}+\eta/\sqrt{6} & \pi^+ & K^+ \\ \pi^- & -\pi^0/\sqrt{2}+\eta/\sqrt{6} & K^0 \\ K^- & \bar{K}^0 & -\sqrt{\frac{2}{3}}\eta \end{bmatrix}$$

$$B = \begin{bmatrix} \Sigma^0/\sqrt{2}+\Lambda/\sqrt{6} & \Sigma^+ & p \\ \Sigma^- & -\Sigma^0/\sqrt{2}+\Lambda/\sqrt{6} & n \\ \Xi^- & \Xi^0 & -\sqrt{\frac{2}{3}}\Lambda \end{bmatrix}$$

$$\xi = \exp\left(\frac{i\Pi}{f}\right)$$

$$V_\mu = \frac{1}{2}(\xi^\dagger\partial_\mu\xi + \xi\partial_\mu\xi^\dagger)$$

$$A_\mu = \frac{i}{2}(\xi^\dagger\partial_\mu\xi - \xi\partial_\mu\xi^\dagger)$$

$$\mathcal{L} = \mathcal{L}^{(1)} + \mathcal{L}^{(2)} + \cdots$$

$$\mathcal{L}^{(1)} = \mathrm{Tr}B_j^\dagger i\partial_0 B_j + i\,\mathrm{Tr}B_j^\dagger[V_0, B_j] - D\,\mathrm{Tr}B_j^\dagger\vec{\sigma}_{jk}\{\vec{A}, B_k\} - F\,\mathrm{Tr}B_j^\dagger\vec{\sigma}_{jk}[\vec{A}, B_k]$$

Gives OBEP for exchange of Goldstone bosons +

$$\begin{aligned}\mathcal{L}^{(2)} = &-\frac{c_1}{f^2}\mathrm{Tr}(B_i^\dagger B_i B_j^\dagger B_j) - \frac{c_2}{f^2}\mathrm{Tr}(B_i^\dagger B_j B_j^\dagger B_i) \\ &-\frac{c_3}{f^2}\mathrm{Tr}(B_i^\dagger B_j^\dagger B_i B_j) - \frac{c_4}{f^2}\mathrm{Tr}(B_i^\dagger B_j^\dagger B_j B_i) \\ &-\frac{c_5}{f^2}\mathrm{Tr}(B_i^\dagger B_i)\mathrm{Tr}(B_j^\dagger B_j) \\ &-\frac{c_6}{f^2}\mathrm{Tr}(B_i^\dagger B_j)\mathrm{Tr}(B_j^\dagger B_i)\ .\end{aligned}$$

Lowest order potential

NN, Ξ N, Ξ Ξ interactions

- **Evaluate Lagrangian**

$$\mathcal{L}^{(2)} \rightarrow \left(c_1 + c_5 + (c_2 + c_6)\frac{1}{2}\right)\left((\Xi^\dagger\Xi)^2 + (N^\dagger N)^2\right) + (c_2 + c_6)\frac{1}{2}\left(\Xi^\dagger\boldsymbol{\sigma}\Xi \cdot \Xi^\dagger\boldsymbol{\sigma}\Xi + N^\dagger\boldsymbol{\sigma}N \cdot N^\dagger\boldsymbol{\sigma}N\right)$$
$$+2(c_3 + c_4\frac{1}{2})\Xi^\dagger N^\dagger N\Xi + 2c_4\frac{1}{2}\left(\Xi^\dagger\boldsymbol{\sigma}N \cdot N^\dagger\boldsymbol{\sigma}\Xi\right)$$

ΞΞ short range potential same as NN

$^1S_0$ channel – OPEP is small for NN

NN scattering length a =-17.3 fm

Same irrep of SU(3)
Nijmegan

If ΞΞ $^1S_0$ POTENTIAL same as for NN:

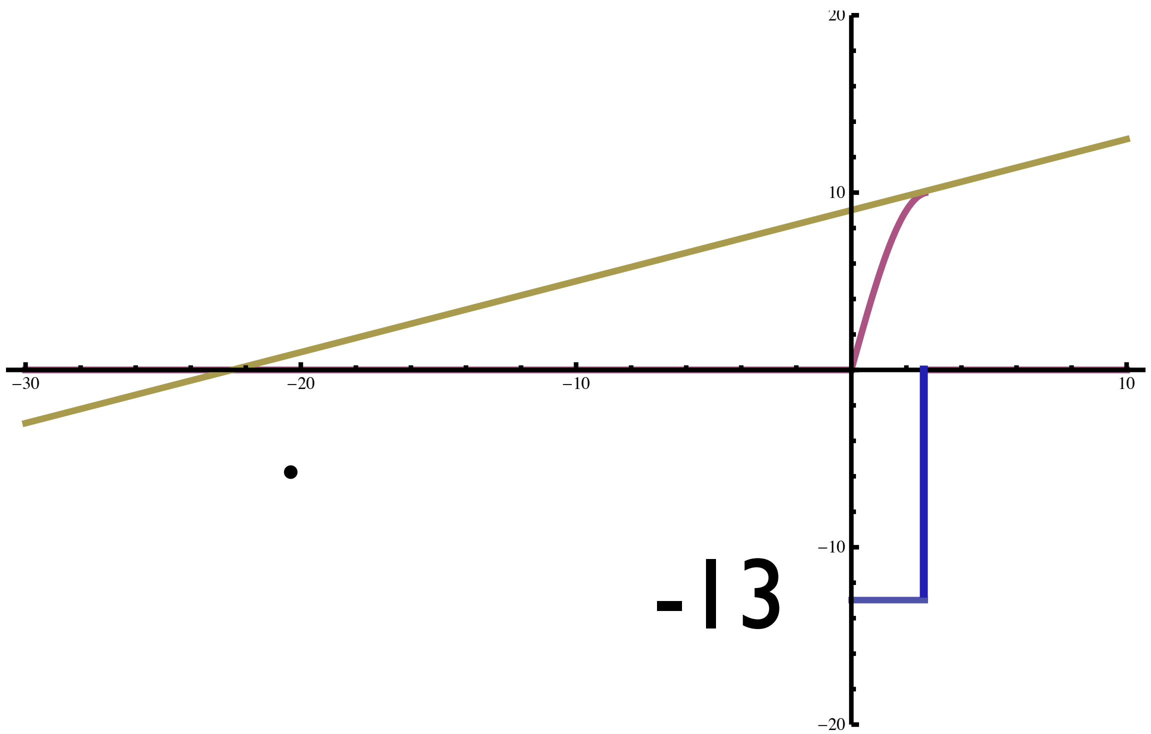
there will be a BOUND STATE dibaryon S=-4, decays

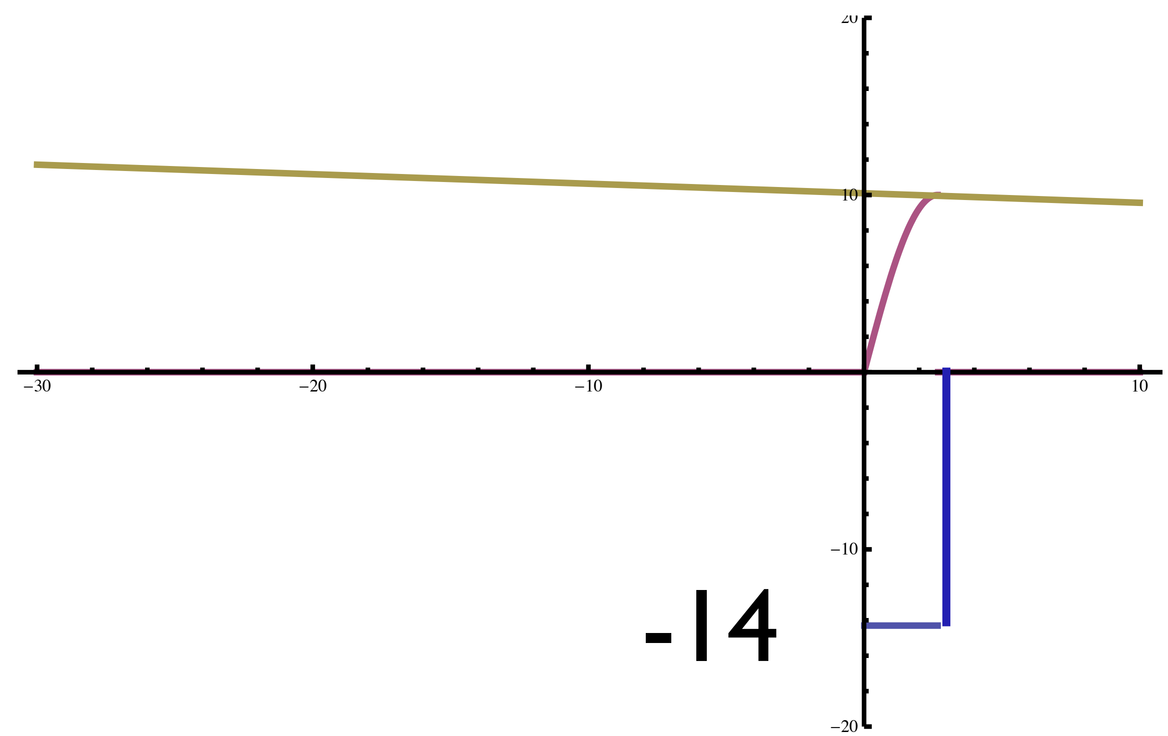
weakly Ξ Λπ

np $^1S_0$ state

Zero energy, 0 potential, wave function: $u(r) = 1 - r/a$

Unbound $a < 0$ | Bound $a > 0$





A little more attraction would give $^1S_0$ bound state

$$-\frac{d^2u}{dr^2} + MVu = k^2u$$

Increase mass M, increases attraction

Three simple two-parameter potentials

- Square well, delta shell, separable
- Fit parameters to experimental np scattering length a, effective range r_e

$$k\cot\delta = -\frac{1}{a} + \frac{1}{2}r_e k^2$$

- Change nucleon mass (940 MeV) to Cascade mass (1315 MeV): 40% increase in attraction
- Each model $\Xi\Xi$ bound $^1S_0$ state B=7.0 , 0.7,0.6 MeV

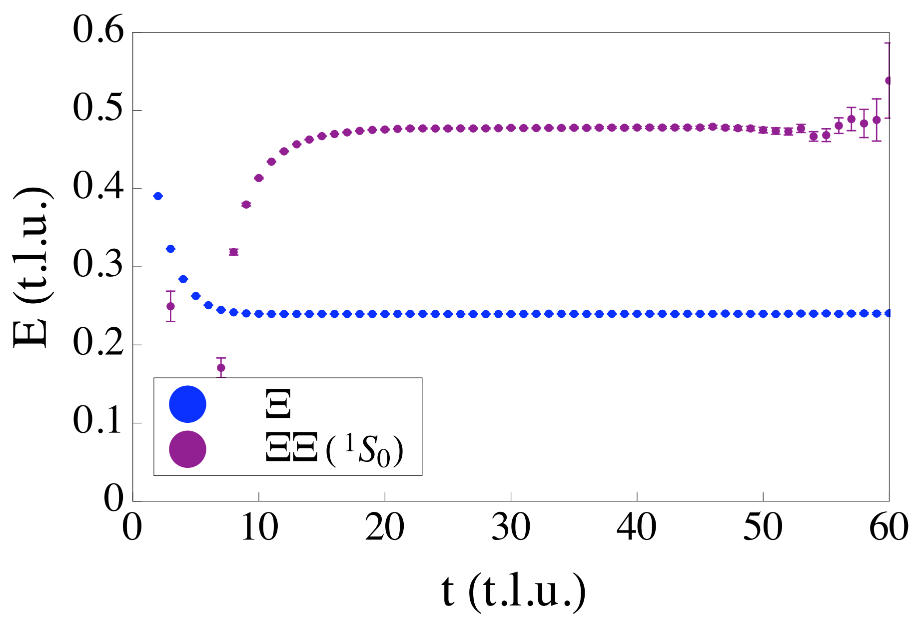
Nijmegan potentials
Stoks, Rijken PRC59,3009
Rijken et al PRC59,21

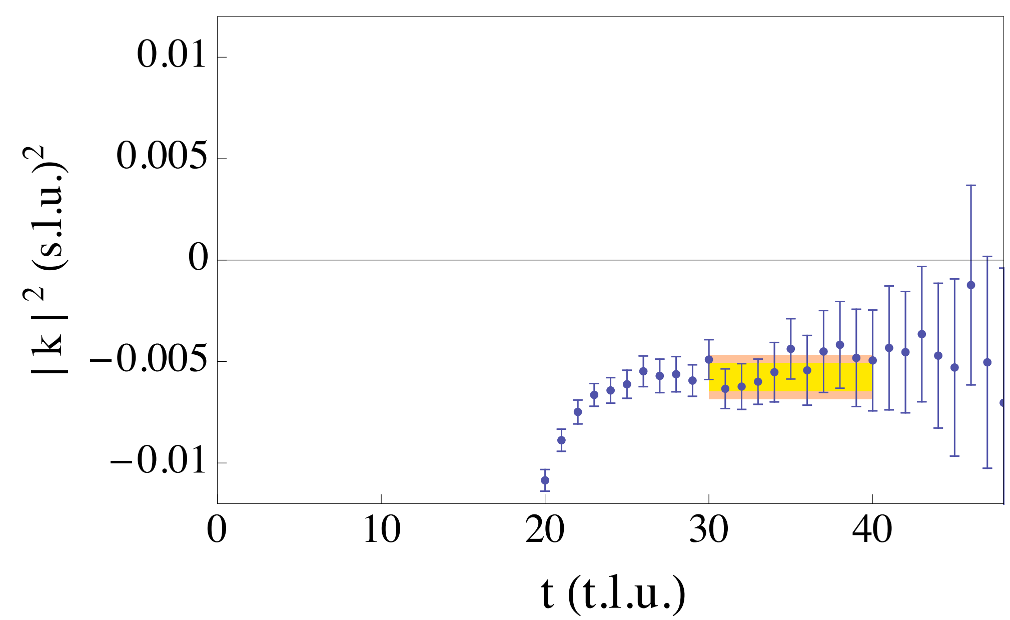
- Soft core BB potentials via one meson exchange
- Form factors give short distance interaction
- quark-pair production ($^3P_0$) simulates flavor symmetry breaking
- Six models constructed to fit all data
- Each model $\Xi\Xi$ bound $^1S_0$ state 0.1 <B<15.8 MeV

Lattice QCD Beane et al 1109.2889

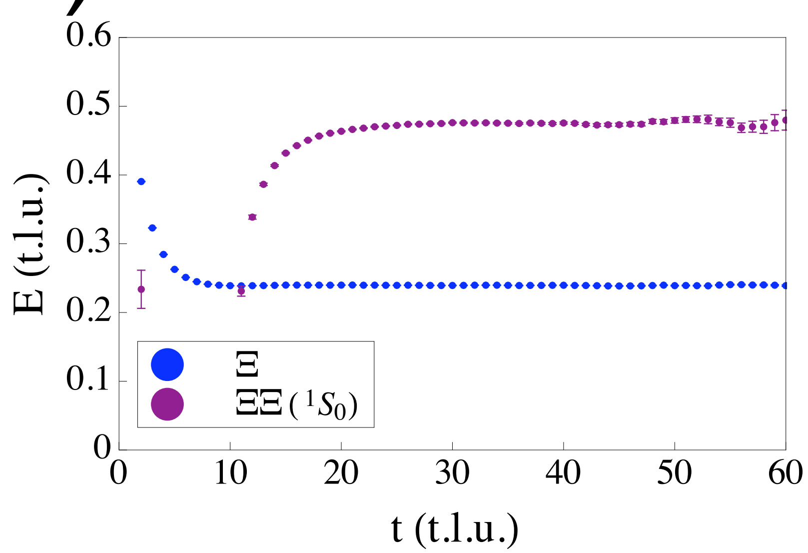
$$m_\pi = 390 \text{ MeV}$$

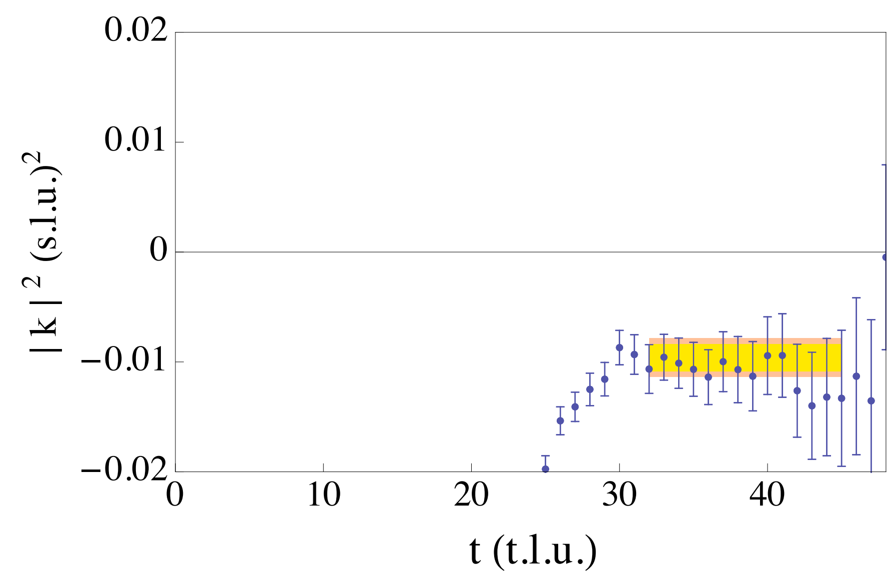
24^3 (128)





32^3 (256)





$$B^{(L=\infty)}_{\Xi^-\Xi^-} = 14.0 \pm 1.4 \pm 6.7 \text{ MeV}$$

9 models plus lattice predict $\Xi\Xi$ $^1S_0$ bound state

- new state of matter
- SU(3) Flavor works
- strange nuclear matter better understood

Finding $\Xi\Xi$ bound states

- $\gamma^{-}D \rightarrow (\ \Xi\Xi\ )$ 4K threshold photon energy **5 GeV** (thanks to R Jones)

Cross sections small due to high momentum transfer at relevant kinematics

- KD $\rightarrow (\ \Xi\Xi\ )$ 3K ?
- RHIC (Huang) can detect decay products $\Xi\Lambda$

Advantages at RHIC

- Plenty of energy to make state
- Need to detect products of weak decays of bound state

Summary

- 9 models plus lattice predict $\Xi\Xi$ $^1S_0$ bound state
- RHIC can detect it